THE INFLUENCE OF WARMING UP

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THE working accuracy of turret lathes both of the horizontal and vertical types depends on the alignment of the axis of the work spindle with the tool holes in the turret head. Every user of turret lathes knows that he must be careful in the morning before the machine has warmed up, to avoid getting scrap pieces, as turret lathes are machines for quantity production, the machine is generally kept in the warmed-up condition for the rest of the day. The use of capstan and combination turret lathes has increased considerably in the last ten years, as it has been evident that the operation of these machines could be done by unskilled or semi skilled, male or female operators, while the supervision and the setting up from five to ten machines could be done by one skilled

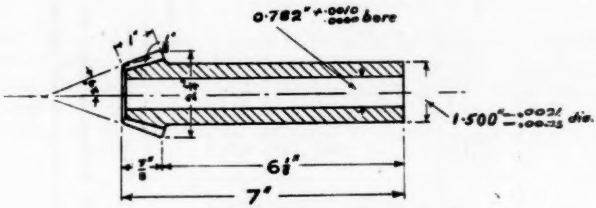


Fig. 1. Bevel gear blank.

setter. Comparison between the ordinary centre lathe and the capstan or turret lathe is justified since with the former there is not the same definite relation between the position of the tools and the position of the main spindle either for chucking work or work between centres. When doing chucking work in a centre lathe any rise of the spindle can easily be compensated for by adjusting the tools on the carriage slide. Besides it is not advisable to use a non-floating reamer in the tailstock for a fixed operation. In the case of work between centres even a considerable vertical deviation (e.g. as much as 0.004 in.) of the main spindle compared with the tailstock gives only a very small and quite permissible deviation from the cylindrical (see Fig. 11).

Fig. 1 shows a bevel gear blank which is taken as a typical job, and the table (Fig. 2) gives the production times for batches of

Number of Pieces	1	1			5	5			10	10			100	100		
	Centre lathe	Capstan lathe			Centre lathe	Capstan lathe			Centre lathe	Capstan lathe			Centre lathe	Capstan lathe		
All Times in Minutes	Total time	Setting	Machin'g	Total time	Total time	Setting	Machin'g	Total time	Total time	Setting	Machin'g	Total time	Total time	Setting	Machin'g	Total time
1 Rough turning hub from bar		26	3	29		5.2	3	8.2		2.6	3	5.6		0.3	3	3.3
2 Finish turning to gauge (smoothing with file and emery stick		25	4	29		5	4	9		2.5	4	6.5		0.3	4	4.3
3 Turning bevel		21	3	24		4.2	3	7.2		2	3	5		0.2	3	3.2
4 Drilling and reaming bore to gauge (four operations)		50	7	57		10	7	17		5	7	12		0.5	7	7.5
5 Parting off		10	0.5	10.5		2	0.5	2.5		1	0.5	1.5		0.1	0.5	0.6
6 Rechucking and finishing second side ...		19	2	21		3.8	2	5.8		2	2	4		0.2	2	2.2
1a Boring and reaming (on chucking machine) .	41				20				18				15			
2a Rough turning on mandrel	27				23				23				22			
3a Finish turning to gauge on mandrel ...	40				34				33				32			
7 Roughing out teeth (universal milling machine)	30			30	14			14	12			12	10			10
8 Finishing on automatic hobbing machine ...	55			55	38			38	25			25	21			21
8a (Alternative method)—planing teeth ...	(80)			(80)	(72)			(72)	(66)			(66)	(65)			(65)
Centre lathe operations against capstan lathe operations	108	against		170.5 (−59%)	77	against		49.2 (+37%)	74	against		34.6 (+53%)	69	against		21.2 (+69%)
Other operations common to both	85			85	52			52	27			37	31			31
Total manufacturing time	193	"		255.5 (−32%)	129	"		101.2 (+21%)	111	"		71.6 (+34%)	100	"		52.2 (+47.8%)
Overall comparison of cost per piece (one piece on centre lathe against 100 pieces on capstan lathe)	193/52.2 = 73% saving.															

Note.—Due to the lower labour costs for capstan operators the saving in cost will be even greater than the saving in time.

Fig. 2. Table comprising production times for various batches of 1-5-10-100 pieces on centre and capstan lathes.

one, five, ten, and 100 pieces. A comparison is made between an ordinary good centre lathe operated by a skilled turner and a capstan lathe set up by a skilled setter and operated by a trained

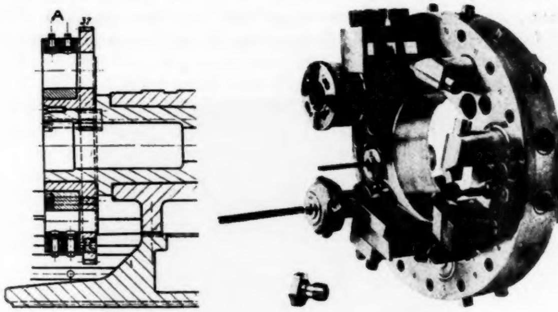


Fig. 3. Interchangeable head (Pittler horizontal turret lathe).

girl. The centre lathe is more economical for one piece, but already for five pieces and over the capstan lathe is superior. By using interchangeable heads, e.g. as in the horizontal turret lathe (Fig. 3) it is not even necessary to repeat the setting up, since it is cheaper to take off the front head complete with tools and store it in the

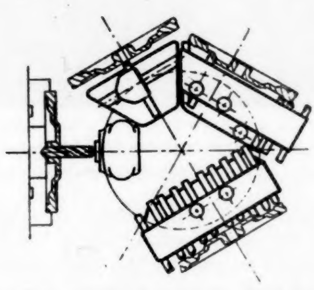


Fig. 4. Interchangeable tool blocks on multi-cutting lathe.

toolroom if the job is to be repeated every month in batches of not less than five.

Of course, this cannot be done in war time where there is a shortage of tools, but all central tools, i.e. those which are located by

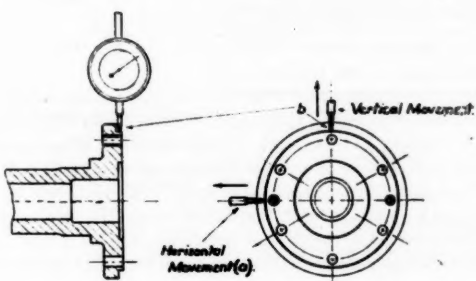
their shanks could be used for the job in the meantime and would only require regrinding and reclamping in the head when the latter was again required. By central tools are meant all those tools with taper shanks fitting into corresponding sockets, such as twist drills, rigid reamers, and counterboring tools, or those with centreing cylinders, such as die-heads, taps, etc. In the example shown in Fig. 3 four drills and one self-opening die-head, or five tools in all,

Fig. 5. Capstan lathe loaded with Prony brake for test purposes.

belong to this class. The same system is applicable to multiple cutting machines where the setting up of the tool black is based on the same principles as used for the turret lathe (Fig. 4).

If in the case of high-speed machines or machines having wide speed ranges, the bearing clearances give trouble in carrying out high-grade precision measurements, the alignment tests (see Fig. 12) should be made on the spindles after they have been run for about one hour with high speed. If necessary, any adjustments of bearings or guides should be made during the setting up of the machine. The working accuracy of a good turret lathe is close. Such a lathe must

turn round within 0.0004 in. with the turret head slide and the cutting-off slide, and turn cylindrically with the turret head slide within 0.0012 in. per foot. Errors in facing with the turret head slide are limited to 0.0008 in. per foot, and the same accuracy is required from the cutting-off slide. These accuracies are much finer than those of our bevel blank. There is no doubt that for the extremely rigid vertical boring mills turning up to 32 in. diameter (operation 1a), at least the working accuracy of the horizontal turret lathe is attained. If the headstock and the main spindle warm up during the course of the day, while the turret head with the tools and the bed remain cold, there are differences horizontally and vertically which may have a decisive influence on the accuracy of all pieces which leave the turret lathe in the finished state. In particular, the position of the axis of the last non-floating finishing reamer in the cold stationary turret is considerably changed with regard to a piece held either in the spring collet or jaw chuck due to the tendency



Spindle Nose to Fig. 6 and Fig. 9.

of the main spindle to rise. These deviations on warming up have been investigated on a well-designed capstan lathe (Fig. 5) and spindle nose to Figs. 6 and 9 with the following results:—

Table 2. Fig. 6 (*a*). The test began at 3-45 p.m. The machine was cold and the thermometer, which had been put into an existing deep screwhole (filled with oil) in the headstock, showed the temperature of the room and headstock to be equal at 13.5°C. The dial gauge on the spigot of the main spindle (Fig. 7 (*a*)] had an accuracy of 0.0001 in. per division and showed +2 ten thousanths.

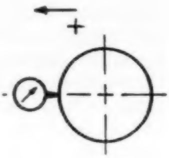
The machine was started and run idle at 131 r.p.m. The whole range of the six speeds was: 71, 131, 241, 453, 834, 1,531. After fifteen minutes (4 p.m.) the temperature was 20° and the clock showed +4 at 834 revs.

CAPSTAN LATHE

FIG. 6.—STARTING TEMPERATURE TESTS—A

Time	Clock indica'r Ten thou.	Pre-tension	Revs. per minute	Temp. °C.
3.45	+2	¾	131	13.5
3.50	+2	—	241	14.5
3.55	+2.5	—	453	16.5
4.00	+4	—	834	20.0
4.05	+4	—	1531	21
4.18	+6	—	1531	25
4.40	+7	—	1531	30
INTERRUPTION				
5.30	+7	¾	1531	26.5
5.55	+8	—	1531	32.1
INTERRUPTION OF ONE DAY—B				
4.15	+9	¾	1531	24
4.55	+12	—	1531	32
5.15	+12	—	1531	35

MACHINE COLD.



FIFTY MINS. STANDSTILL.

HORIZONTAL EXPANSION.

MACHINE WAS WARM

RUNNING THE WHOLE FORENOON.

Table A—afternoon of first day.
Table B—afternoon of second day.
Horizontal influence of warming up.
Stationary dial-gauge hand on spigot of spindle.

Fig. 6. Table of results— (A) **Afternoon of second day.**
(B) **Afternoon of third day.**

At 4-18 the readings were: Temperature 25°, clock +6, 1,531 revs.; and at 4-40 they were: Temperature 30°, clock +7 (0.0007 in. rise), 1,531 revs. This was about an hour after starting. The total horizontal deviation was 7 — 2=5=0.0005 in. This is just the permissible tolerance for a sliding fit for a piece of 1½ in. Now the machine was stopped intentionally. After fifty minutes standstill the temperature decreased from 30° to 26.5°C. without influencing the horizontal position of the spindle; then the spindle was run another twenty-five minutes up to 5.55 p.m. with the maximum speed of 1,531, raising the temperature to 32.1° and causing an increase of the horizontal deviation of 8 — 7=0.0001 in., which is negligible for this time, but not in relation to the time of beginning, 3-45 p.m. Here the total difference of 8 — 2=6 divisions or 0.0006 in. clock indication is not permissible for many transition

fits and some interference fits, and is dangerous for tight running fits as fixed by the B.S.I. Standards No. 164. As a result we can state that after an hour's initial running the machine is so well warmed up that the horizontal deviation remains unchanged and fairly small for the whole working day, so that it can be neglected in some cases. All tools which work from the horizontal position

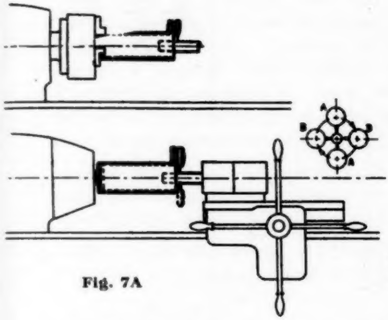


Fig. 7A

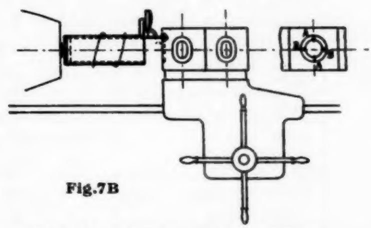


Fig.7B

Fig. 7, Arrangement of dial gauges—
(A) Tubular arm for turn-round method for holes.
(B) Tubular arm for turn-round method for recesses.

against the piece externally would produce undersize pieces because the tool which is in the position of the dial gauge remains stationary, whereas the piece is moving against the tool. Compare the dotted line in Fig. 8. The tests were continued in the afternoon of the next day, but the machine had been run in the morning loaded by a Prony brake (Fig. 5), and remained warm after stopping it at 12-15 p.m., when its temperature was 39.6°C. The machine was restarted and run idle at 4-15 p.m. after four hours, standstill, with

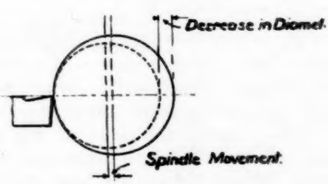
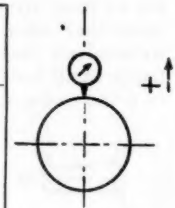


Fig. 8. Effect of horizontal movement on diameter of work.

the maximum speed of 1,531 revs. [Table Fig. 6 (*b*)]. The temperature rose in one hour (4-15 to 5-15 p.m.) from 24° to 35°C., and the clock moved from 9 to 12=0.0003 in., which is in many cases negligible. As a result we can state that a long standstill of the warmed-up machine does influence the horizontal expansion, but only by a negligible amount as far as the accuracy of pieces

Fig. 9. A

Time first day	Clock indica'r Ten thou.	Pre-tension	Revs. per minute	Temp. °C.	REMARKS
9.40	— 2	¼	71	14.2	FIRST HOUR.
9.48	0	—	131	16	
9.58	0	—	241	17.5	
10.03	+ 4	—	453	18.8	
10.10	+ 5	—	834	20.5	
10.15	+ 7	—	1531	22	
10.30	+14	—	1531	25	
10.45	+20	—	1531	30	
11.00	+22	—	1531	32	SECOND HOUR.
11.15	+22	—	1531	34	
11.30	+23	—	1531	35.8	
11.45	+24	—	1531	37.5	
12.00	+24	—	1531	38.7	
12.15	+25	—	1531	39.6	



QUICK STARTING (SECOND DAY)—B

9.52	+ 1	¼	0	11	COLD.
10.00	+ 1	—	71	11	SLOW SPEED.
10.01	+ 1	—	131/241	11.2	
10.05	+ 1	—	453	12.1	TWENTY-THREE MINUTES. FAST SPEED.
10.10	+ 2	—	43	15.5	
10.12	+ 2.5	—	834	16.2	
10.15	+ 4	—	1531	17.2	
10.22	+11	—	1531	19.1	
10.45	+17	—	1531	26.0	
10.52	+17.5	—	1531	27.5	

Table A—upper part first day/forenoon.
Table B—below second day/forenoon.
Vertical influence of warming up.
Stationary dial-gauge on top of spigot.

Fig. 9. Table results—
(A) Forenoons of first and second days.
(B) Forenoon of fourth day.

manufactured after the first hour is concerned. The total horizontal deviation of +2 to +12=0.001 in. would be by no means permissible. Next, the *vertical* change due to temperature rise (which is a decisive factor for the good performance of the machine) was investigated. Table Fig. 9 (*a*) shows a test of one hour from 9-40 a.m. to 10-45 a.m. The revolutions were changed in steps from 71 to 1,531, and the machine was loaded up to 2 h.p. The temperature increased from 14.2 to 30°C, and the spindle rose from —2 to +20 divisions of the clock +0.0022 in. [Fig. 9 (*b*).] Using a rigidly held reamer (Fig. 10), the bore would have 2×0.0022 in.=0.0044 in. error, which is six times more than the permissible tolerance for a 1½ in. diameter bore made to accuracy B and three times more than that for accuracy U.

(The B.S.I. tolerance standard limits are: +0.0007 in. for most accurate holes (B), +0.0014 in. commonly used accuracy (U), +0.0028 in. larger tolerances (V].

Fig. 9 (*a*) also shows readings for the following hour from 11 to 12, with a constant speed of 1,531 revs., a temperature rise from

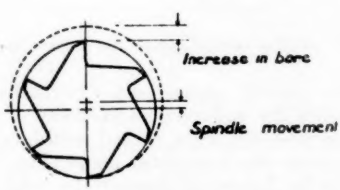


Fig. 10. Effect of vertical spindle rise on fixed reamer.

32° to 38.7°C., and a vertical movement from 22 to 24=2 divisions. Thus the temperature rose very slowly and the deviation remained within permissible limits. This shows that for one hour after the first the operator can work undisturbed by the changes of the warmed-up headstock in both directions.. This is an important result. The workman must know during the first hour that the machine is going up, and the setter has to arrange the tools in such a way that the vertical change does no harm. It may occur that early in the morning urgent work is required from the machine, with high speeds, and there is no time to wait for an hour before quantity production may be started without danger of producing scrap.

There Fig. 9 (*b*) shows a rapid starting of the machine. The cold machine (11°C.) was run up from standstill to 1,531 revolutions (idling) in twenty-three minutes (9.52 to 10-15 a.m.). The tem-

perature rose from 11° to 17.2°C. and moved the spindle upward from 1 to 4=0.0003 in. This would have been negligible, but now the influence of warming-up increased in the next thirty-seven minutes (from 10.15 to 10.52 a.m.) from 4 to 17.5=0.00165 in. which was already far too much, and was still further increased up to 40° in another hour, when the deviation reached +0.0027 in. for the rigid reamer [Table, Fig 9 (*a*), beginning from —2]. This means 2×0.0027 in.= 0.0054 in. increase of the bore, and the production of scrap.

Result. The vertical rise of the spindle would make manufacturing in quantities dangerous for the first hour at least. The operator must have instructions to pay great attention to all tools

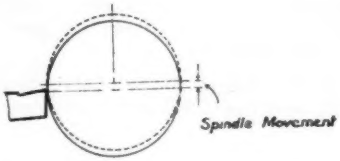


Fig. 11. Effect of vertical spindle rise on external tools.

which work in the vertical plane, both externally and internally. The setter can nullify the bad vertical influence of the unavoidable and irresistible warming-up, by a skilled setting-up and adjusting of all external tools in the horizontal plane (Fig. 11), so that the vertical movement is following tangentially and does negligible harm. Of course, the influence and adjustment of the steadies must be carefully watched.

Regarding the bores, however, such an expedient does not exist for multiple point tools such as twist-drills, countersinking bits and rigid reamers which double the error of the eccentric position. For external cutting tools the influence is negligible if they are correctly set up, and, further, they can be adjusted easily. For the last reamer there is no other means than to make it floating. It then becomes a self-adjusting tool which moves up with the changed position of the main spindle. (But try never to use floating taps or dies.) The tool holes in the turrets of horizontal and vertical turret lathes ought not to be bored until the machine has run at least an hour (better two hours for big machines as vertical boring mills), so that the main spindle is in the working position of the warmed-up machine; if the holes of the turret head are then bored and reamed they are aligned for the working machine and for quantity production. This state is important.

The results from an alignment test made on the machine (Fig. 12) show clearly that this had been done. The axes of all the turret holes averaged 0.00279 in. higher than the spindle axis when the machine was cold, and this was compensated for by the

ACCEPTANCE TESTS

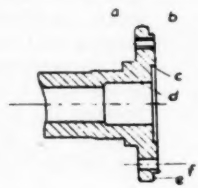
	Permissible Error				
Test	Accept'ce test charts	British	American	Actual error	Remarks
Centring sleeve for true running	0.0004"	0.0004" B.M.T.E. Spt.-Oct. 1938).	0.0005"	*a* .00025" *b* .0001" *c* .0002" *d* .0000" *e* .0001" *f* .0001"	
Tool holes aligned with work spindle in vertical plane. (Tool hole axes higher than axis of cold spindle). Fig. 7a.	0.0008" high only (warmed up machine.)		0.001" high only	Hole No. 1 .00285" 2 .0028" 3 .00273" 4 .00282" 5 .00276" 6 .00274" Average .00279 high	Measurements were made in *cold* state. Warming up raised the spindle .0027" thus compensating for error and reducing it to approximately .00009".
Ditto, in horizontal plane. Fig. 7a.	.0008" either way		0.001" either way	Hole No. 1 .00125" 2 .00127" 3 .00111" 4 .00126" 5 .00124" 6 .00120" Average .00122"	Away from operator. Warming up compensated for .0010" reducing error to .00022".
Centring recesses aligned with work spindle in vertical plane. Fig. 7b.	0.0008" high only		0.001" high only	Hole No. 1 .00272" 2 .00262" 3 .00266" 4 .00263" 5 .00260" 6 .00262" Average .00264"	Upwards. Compensated for .0027" by warming up, reducing error to appx. .00006".
Ditto, in horizontal plane. Fig. 7b	0.0008" either way.		0.001" either way.	1 .00118" 2 .00120" 3 .00074" 4 .00108" 5 .00094" 6 .00096" Average .00102"	Away from operators. Error reduced to .00002". Compensation .0010"

Fig. 12. Measurements taken from alignment tests.

spindle rise of 0.0027 in., leaving only an error of approximately 0.00009 in. Similarly, warming up reduced the average horizontal "cold" error from 0.00122 in. to approximately 0.0004 in. Fig. 12 also gives the corresponding limits laid down by the writer in "Testing Machine Tools" and by a first-class American maker, which emphasise the high quality of our British machine.

The objection that for the first hour the tools of the cold machine are in a higher position than for the other working hours of the day is not so important, because an operator has to wait at least half an hour before he begins real manufacturing, and after this first half hour the machine is warmed up sufficiently to avoid scrap—particularly if in this half hour the workman does rough turning and boring. Twist-drills have 0.01 to 0.02 in. allowance, and in performing all the roughing operations the warming-up is accelerated very much. There is no remedy by changing the design, because the influence of heat and the extension of the heated components are inevitable. Their effects can, however, be reduced by the methods outlined above.

QUARTERLY REPORT

(January to March)

During the last three months the Research Department has been working on—

(1) Surface finish.

(2) Acceptance test charts.

(3) Cutting tools.

(4) Cutting oils.

Re (1). The report on surface finish was delayed because the Joint American Standards Committee of the American Society of Mechanical Engineers and the Automotive Engineers has now published a proposal for Standard B.46 of surface roughness. In this proposal the Americans restrict the standard to one single parameter: the h_{rms} value of the irregularities. This parameter is associated with the Abbot-Profilometer. About 120 of these instruments are in use, a few in this country and the majority in the United States. The results of our tests do not exactly conform with the American proposals. We would not recommend as a rule one single parameter, which can never comprise all the properties of a surface (fineness, load carrying area, minimum of friction, etc.). We believe further that the h_{rms} value is a conventional measure of average ridges and is too complicated for the simple understanding of the shop people such as inspectors, foremen and fitters who work with these instruments. Even in the laboratory such a value could be replaced by a more simply defined quantity. But we must carefully consider the American progress laid down in the following publications :—

(1) Report of Summer Conference on "Friction and Surface Finish" at the Massachusetts Institute of Technology, including nine very instructive papers on finishing, friction, wear and metallurgy (published June, 1940). The papers cover 140 pages, and the discussion 104 pages. These proceedings of the Boston Summer Conference are of the greatest importance for all who are interested in surface finish and its practical use.

(2) "The Story of Super-finish," by Arthur M. Swigert, Junr., Director of Production Research of the Crysler Corporation; 656 pages (published in September, 1940). These publications have been carefully studied by the director and will be taken into consideration in the final report. Almost the entire staff is now working on the report on surface finish.

Re (2). Seven acceptance test charts, including—

(1) Capstan and combination turret lathes.

(2) Single and double standard vertical boring mills.

(3) (*a*), (*b*), (*c*), (*d*), the four-surface grinding machines.

These charts are now ready for publication. The Director recommends that a joint meeting be held with the Institution of Mechanical Engineers to decide if this publication is opportune. Then the necessary duplicates or prints of the seven new test charts, including 82 small blocks (etchings) must be prepared. In accordance with the decision of the meeting of March 10, the Research Department is continuing its work preparing acceptance tests for—

(1) Tool-room lathes.

(2) Single spindle automatics.

(3) Multiple spindle automatics.

(4) Horizontal boring mills.

(5) Planing machines.

(6) Shaping machines.

(7) Slotting machines.

It is of the greatest importance that the National Machine Tool Builders' Association, Cleveland, U.S.A., began to publish their first Acceptance Test Charts as standards for all engine lathes in February, 1941.

Re (3). In view of the extensive roughing tests completed by previous workers in cutting tool research for the determination of cutting angles, etc., for various materials, further roughing tests do not appear to be necessary. The only development is an increase of speed, and this increase of speed is only possible if the existing machine tools have sufficient power. Generally the bearings, the lubrication and the gears are not designed for higher speeds, consequently for the time of war the speeding up of roughing cuts is not so important. Only those manufacturers of armament parts who are able to get new modern high-speed machine tools can take advantage of the improved capacity of modern cemented carbides which permit interrupted cuts without chipping and breaking the cutting edge and which allow in some cases to double and treble the cutting speed. Increasing the speed, however, means increasing the motor power in the same relation and this is not in all cases advisable or even possible.

The Research Department tested the most modern cutting tools for semi-roughing cuts on chromium nickel steels, taking cuts up to $\frac{1}{4}$ in. deep and .040 feed, with speeds up to 600 ft. and utilising over 48 h.p. For this purpose the director of the L.M.S. Railway gave permission

to use their heavy high-speed testing lathe in conjunction with the instruments supplied by the Research Department. The conditions of finishing cuts, however, are in very many cases of greater importance, because well-lapped cemented carbide tools with correct angles and high speeds achieve most useful fine finished surfaces. Therefore the Research Department concentrated its efforts on the development of measuring instruments for this purpose. The apparatus for measuring small forces down to 1 lb. cutting form are developed and calibrated.

The tests shall be made on three different steel materials (axle steel of 40 tons/sq. in. manganese steel of 220 Brinell hardness, 60 tons/sq. in., and very tough and hard heat-treated Cr-Ni steel (3.5 Ni) of 370 Brinell hardness 80 tons/sq. in.; further on cast iron of 150 Brinell hardness).

Re (4). We intend to test the efficiency of cutting oils, keeping all data constant with the exception of the cutting oil. For this purpose a drilling machine and a $\frac{5}{8}$ in. high-speed drill, cobalt-tungsten alloy will be used. A new drill performance tester will be set up during the coming months, capable of measuring exactly the torque and the thrust of the drill. If the cutting oil increases the tool life under very severe conditions of speed and feed on hard material, and if the torque and thrust are decreased, it will be an improvement for the workshop.

The other properties of a good cutting oil—(1) non-corroding, (2) non-smelling, (3) non-damaging the skin of the operator—are assumed as a matter of course.

G. Schlesinger,
Director of Research.

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